Finanziato dall'Unione europea NextGenerationEU

Ministero dell'Università e della Ricerca

Italiadomani PIANO NAZIONALE DI RIPRESA E RESILIENZA

Università degli Studi di Messina

Missione 4 Istruzione e Ricerca

ATHENA

A novel approach Towards the management of building materials of particular Historical-artistic interest: assessment of the radon Exhalation and the radiological risk due to Natural radioActivity content

(PNRR - Missione 4, Componente 2, Investimento 1.1 - Bando Prin 2022 PNRR - Decreto Direttoriale n. 1409 del 14-09-2022)

CUP J53D23014560001 - codice identificativo P2022CPA2K

Which target?

The main target of the ATHENA project is to define an innovative protocol for the systematic characterisation of construction materials used in buildings of particular historical and artistic interest, particularly in terms of radon gas exhalation rates.

Why it is important what we do

The development of ad-hoc techniques and protocols for the quantitative assessment of the natural radioactivity content in building materials, pre- and post-treatment (ageing, consolidation) can play a key role in the field of cultural heritage, considering that materials potentially enriched with radionuclides of natural origin have been used in the past to construct monuments of particular historical and artistic interest.

The research group

Unit 1 – University of Messina(68.707 Euro)
Caridi Francesco (P.I.) https://unime.unifind.cineca.it/get/person/026777
Venuti Valentina https://unime.unifind.cineca.it/get/person/010171
Majolino Domenico https://unime.unifind.cineca.it/get/person/009121

Unit 2 – University "Mediterranea" of Reggio Calabria (56.077 Euro)
Faggio Giuliana (unit head) https://www.unirc.it/scheda_persona.php?id=50430
Messina Giacomo Domenico Savio https://www.unirc.it/scheda_persona.php?id=101

Unit 3 – University of Salerno (31.663 Euro)
Guida Michele (unit head) https://rubrica.unisa.it/persone?matricola=001295

Unit 4 – University of Calabria (21.336 Euro)
Ruffolo Silvestro Antonio (unit head) https://www.unical.it/storage/teachers/silvestro.ruffolo/
Ponte Maurizio https://www.unical.it/storage/teachers/maurizio.ponte/

Unit 5 – University of Cagliari (28.966 Euro)
Da Pelo Stefania (unit head) https://web.unica.it/unica/page/it/stefania_dapelo
Chiriu Daniele https://web.unica.it/unica/page/it/daniele_chiriu

Skills

The five research units (RUs) involved in the ATHENA project constitute a 'scientific' network with complementary expertise,
including sampling of cultural heritage building materials, assessment of radon exhalation rates, mineralogy and radiological risk assessment due to natural radioactivity content, up to accelerated ageing, treatment with consolidants and assessment of radon exhalation after treatments.
The team is well-mixed in that it combines the expertise of the ATHENA project PI in the field of radiological risk assessment due to radioactivity content in environmental samples with that of the other participants, experts in, among others:
– products and procedures for the conservation of stone materials belonging to the Built Heritage;
– assessment of radon gas exposure and exhalation rates in the context of cultural heritage;
– structural and physico-chemical characterisation of materials, including those of particular historical and artistic interest.

The synergy between all components of the ATHENA project can guarantee a favourable outcome of the project itself, with a high impact in the field of environmental quality, in particular for a better protection of historical sites and monuments.

Milestones

MILESTONE 1

To assess any possible radiological risk for the human beings related to outdoor exposure to gamma rays from building materials of interest in the field of cultural heritage.

MILESTONE 2

To identify the most effective long-stable consolidating agent which minimize the radon exhalation rate while maintaining high compatibility with the substrate, in view of a rationalized selection of a restoration procedure to be applied to building materials.

MILESTONE 3

To clarify the correlation between the fundamental properties of the investigated building stones and the calculated radon exhalation rates, in order to improve the indoor environmental air quality.

Milestone 1

ACTIVITY	ASSIGNED TO	I year						II year					
		BIM. 1	BIM. 2	BIM. 3	BIM. 4	BIM. 5	BIM. 6	BIM. 1	BIM. 2	BIM. 3	BIM. 4	BIM. 5	BIM. 6
Sampling	RUFFOLO S	X	X										
Mineralogy and radiological risk assessment due to the natural radioactivity content	CARIDI F FAGGIO G			X	X	X	X	X	X				

The **first milestone** of the ATHENA project, to be achieved by the 16th month of the project (February 2025), is associated with the following deliverables:

Deliverable 1.1: Measurement of the specific activity of the naturally occurring radioactive elements, such as Ra-226, Th-232 and K-40, contained in the investigated building materials by using High Purity Germanium (HPGe) gamma-ray spectrometry and assessment of any possible radiological risk for the human beings through the calculation of the following indexes: activity concentration index (I), alpha index (Iα), absorbed gamma dose rate (D), radium equivalent activity (Ra_{eq}), hazard indexes (H_{in} and H_{ex}), annual effective dose equivalent outdoor ($AEDE_{out}$) and excess lifetime cancer risk (ELCR).
A Technical Report of the obtained results will be released upon completion, by the 16th month of the ATHENA project.

Deliverable 1.2: Identification of the main radioisotope-bearing minerals responsible of the naturally occurring radionuclides present in the investigated samples (Technical Report of the obtained results) through X-ray Diffraction (XRD) and Micro-Raman Scattering (MRS) measurements.
A Technical Report of the obtained results will be released upon completion, by the 16th month of the ATHENA project.

Milestone 2

ACTIVITY	ASSIGNED TO	I year						II year					
		BIM. 1	BIM. 2	BIM. 3	BIM. 4	BIM. 5	BIM. 6	BIM. 1	BIM. 2	BIM. 3	BIM. 4	BIM. 5	BIM. 6
Sampling	RUFFOLO S	X	X										
Assessment of the radon exhalation rate before treatment	GUIDA M. DA PELO S		X	X	X	X							
Accelerated aging, treatment with consolidant and evaluation of the radon exhalation	GUIDA M. RUFFOLO S DA PELO S			X	X	X	X	X	X	X	X	X	

The **second milestone** of the ATHENA project, to be achieved by the 22nd month of the project (September 2025), is associated with the following deliverables:

Deliverable 2.1: Assessment of the radon exhalation rate for the untreated investigated cultural heritage building materials by using the Closed Chamber Method (CCM).
A Technical Report of the obtained results will be released upon completion, by the 9th month of the ATHENA project.

Deliverable 2.2: Evaluation of the radon exhalation by using the CCM after laboratory treatments of the investigated materials, i.e. accelerated aging tests together with consolidation through the use of different selected commercially-available consolidants.
A Technical Report of the obtained results will be released upon completion, by the 22nd month of the ATHENA project.

Milestone 3

ACTIVITY	ASSIGNED TO	I year						II year					
		BIM. 1	BIM. 2	BIM. 3	BIM. 4	BIM. 5	BIM. 6	BIM. 1	BIM. 2	BIM. 3	BIM. 4	BIM. 5	BIM. 6
Sampling	RUFFOLO S	X	X										
Laboratory-treated samples characterization	CARIDI F RUFFOLO S			X	X	X	X	X	X	X	X	X	

The **third milestone** of the ATHENA project, to be achieved by the 22nd month of the project (September 2025), is associated with the following deliverables:

Deliverable 3.1: Evaluation of the porosity, roughness, crystalline abundance, penetration depth of consolidant products, and other petrographical and textural features of the laboratory-treated construction materials through Scanning (SEM) Electron Microscopy, also associated with Energy Dispersive X-rays spectroscopy (EDX).
A Technical Report of the obtained results will be released upon completion, by the 18th month of the ATHENA project.

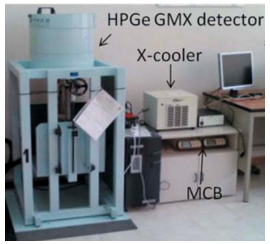
Deliverable 3.2: Characterization of the laboratory-treated building materials at elemental and molecular scales through InfraRed (IR), X-Ray Fluorescence (XRF) and Raman spectroscopy and microspectroscopy.
A Technical Report of the obtained results will be released upon completion, by the 22nd month of the ATHENA project.

Gantt diagram

	Activity	Role of each RU		Duration (months) 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
WP1 Leader: RU1-UniME	Administration	RU1-UniME/RU2-UniRC/RU3-UniSA/RU4-UniCS/RU5-UniCA	i) Overall project management, financial management, steering group/consortium meetings and formal reporting	
WP2 Leader: RU4-UniCS	Sampling	RU4-UniCS	i) Collection of cultural heritage building materials	
WP3 Leader: RU3-UniSA	Assessment of the radon exhalation rate	RU3-UniSA	i) Measurement of the radon exhalation rate	
		RU5-UniCA		
WP4 Leader: RU1-UniME	Mineralogy and radiological risk assessment due to the natural radioactivity content	RU1-UniME	i) Characterization by HPGe gamma spectrometry and radiological risk assessment	
			ii) Characterization by µRaman	
		RU2-UniRC	i) Characterization by XRD	
WP5 Leader: RU4- UniCS	Accelerated aging, treatment with consolidant, samples characterization and evaluation of the radon exhalation	RU4-UniCS	i) Accelerated aging	
			ii) Treatment with consolidants	
			iii) Characterization by SEM, SEM-EDX	
		RU1-UniME	i) Characterization by IR, XRF and Raman	
		RU3-UniSA	i) Measurement of the radon exhalation rate	
		RU5-UniCA		
WP6 Leader: RU1-UniME	Dissemination	RU1-UniME/RU2-UniRC/RU3-UniSA/RU4-UniCS/RU5-UniCA	i) Brochure/flyer, educational material, posters	
			ii) Web-site	
			iii) Scientific publications	
			iv) Strategic planning of communication, meetings among the partners, final plenary meeting	
			v) Seminars, ex-cathedra and e-learning program	

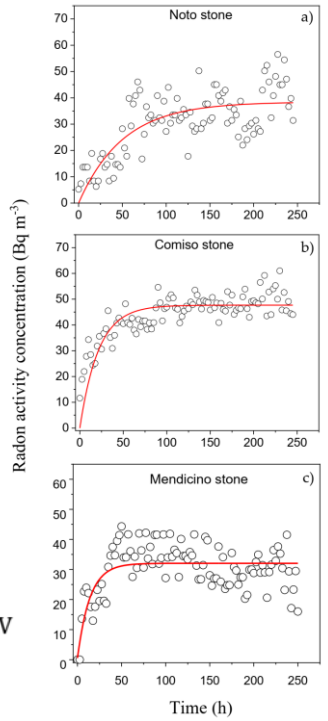
Publications

1. F. Caridi, D. Chiriu, S. Da Pelo, G. Faggio, M. Guida, G. Messina, M. Ponte, S.A. Ruffolo, D. Majolino, V. Venuti
   Radon exhalation rate, radioactivity content and mineralogy assessment of building materials of particular historical-artistic interest
   Applied Sciences, submitted



$$C\ (\mathrm{Bq\ kg^{-1}\ d.w.}) = \frac{N_E}{\varepsilon_E t \gamma_d M}$$

$$E = \frac{(C - C_0 e^{-\lambda T})/m}{1 - e^{-\lambda T}} \lambda V$$



Sample	^{222}Rn exhalation rate (Bq h^{-1} kg^{-1})
Noto stone	0.013 ± 0.003
Comiso stone	0.040 ± 0.006
Mendicino stone	0.030 ± 0.010

Sample	Activity concentration		
	C_{Ra} (Bq kg^{-1})	C_{Th} (Bq kg^{-1})	C_K (Bq kg^{-1})
Noto stone	14.5 ± 1.6	0.99 ± 0.16	6.2 ± 0.8
Comiso stone	21.9 ± 1.9	1.8 ± 0.3	3.2 ± 0.4
Mendicino stone	8.6 ± 0.7	9.4 ± 0.8	169 ± 23

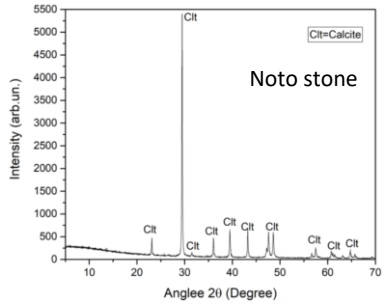
Sample	D (nGy h^{-1})	AEDE (μSv y^{-1})	ACI	I_α
Noto stone	14.9	73.2	0.06	0.07
Comiso stone	22.4	110	0.08	0.11
Mendicino stone	31.8	156	0.13	0.04

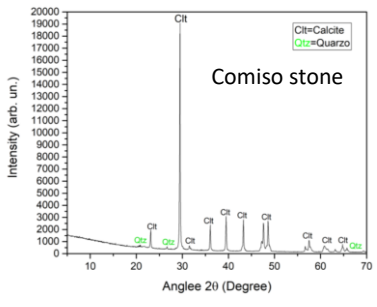
$$D\ (\mathrm{nGy\ h^{-1}}) = 0.462C_{Ra} + 0.604C_{Th} + 0.0417C_K$$

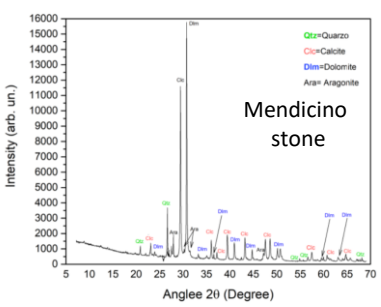
$$AEDE = D \times 8760\ \mathrm{h} \times 0.7\ \mathrm{Sv\ Gy^{-1}} \times 0.8 \times 10^{-6}$$

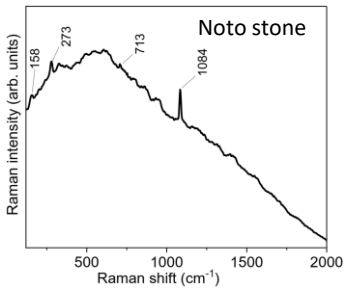
$$ACI = (C_{Ra}/300 + C_{Th}/200 + C_K/3000)$$

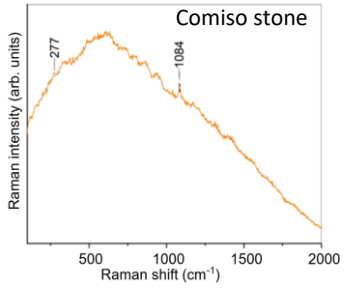
$$I_\alpha = C_{Ra}/200$$

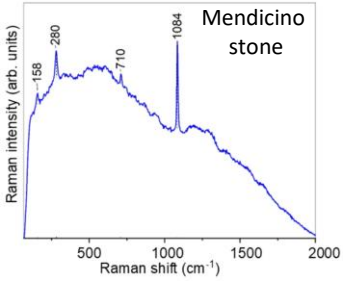








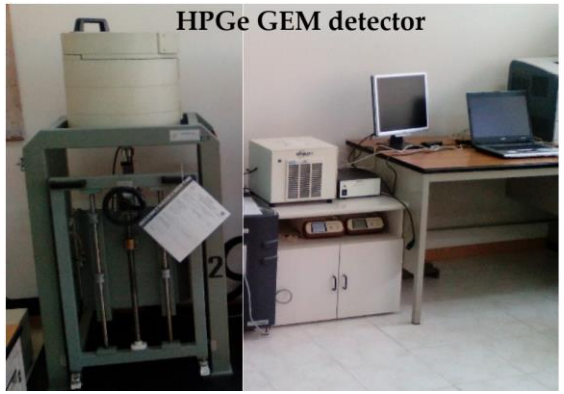


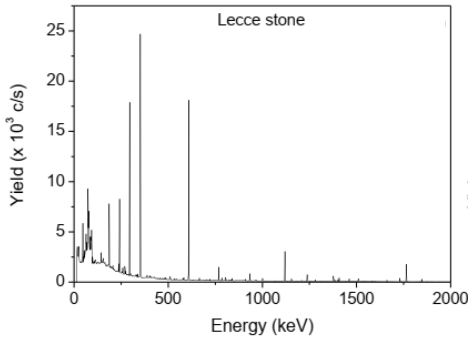


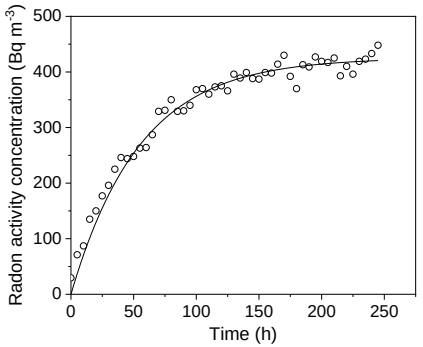
2. F. Caridi, D. Majolino, V. Venuti, D. Chiriu, S. Da Pelo, G. Faggio, G. Messina, M. Guida, M. Ponte, S.A. Ruffolo

Assessment of the radon exhalation and the radiological risk due to natural radioactivity content in the "Pietra di Lecce" building material: a case study

WSEAS Transactions on Environment and Development, in press







$$C\ (\mathrm{Bq\,kg^{-1}\ d.w.}) = \frac{N_E}{\varepsilon_E t \gamma_d M}$$

$$E = \frac{(C - C_0 e^{-\lambda T})/m}{1 - e^{-\lambda T}} \lambda V$$

$$D\ (\mathrm{nGy\ h^{-1}}) = 0.462C_{Ra} + 0.604C_{Th} + 0.0417C_K$$

$$AEDE_{out}\ (\mathrm{mSv\ y^{-1}}) = D\ (\mathrm{nGy\ h^{-1}}) \times 8760\ \mathrm{h} \times 0.7\ \mathrm{Sv\ Gy^{-1}} \times 0.2 \times 10^{-6}$$

$$AEDE_{in}\ (\mathrm{mSv\ y^{-1}}) = D\ (\mathrm{nGy\ h^{-1}}) \times 8760\ \mathrm{h} \times 0.7\ \mathrm{Sv\ Gy^{-1}} \times 0.8 \times 10^{-6}$$

$$Ra_{eq}\ (\mathrm{Bq\ kg^{-1}}) = C_{Ra} + 1.43C_{Th} + 0.077C_K$$

$$H_{ex} = (C_{Ra}/370 + C_{Th}/259 + C_K/4810)$$

$$H_{in} = (C_{Ra}/185 + C_{Th}/259 + C_K/4810)$$

$$I = (C_{Ra}/300 + C_{Th}/200 + C_K/3000)$$

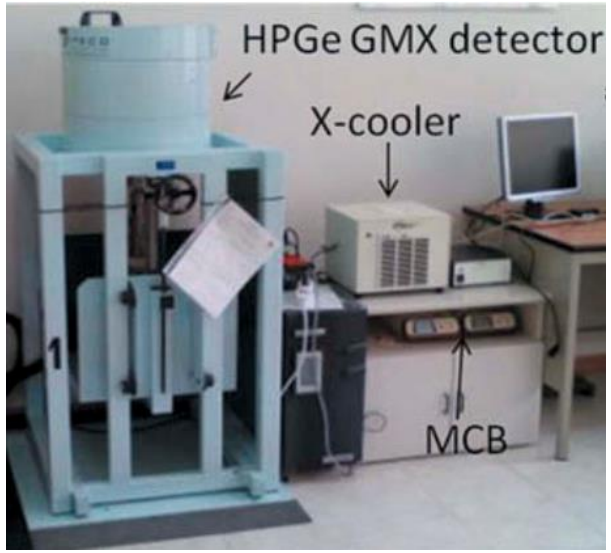
Sample	^{222}Rn exhalation rate (Bq h^{-1} kg^{-1})	Specific activity C_{Ra} (Bq kg^{-1} d.w.)	C_{Th} (Bq kg^{-1} d.w.)	C_K (Bq kg^{-1} d.w.)
Pietra di Lecce	0.156 ± 0.019	163 ± 27	0.9 ± 0.2	22.4 ± 4.6

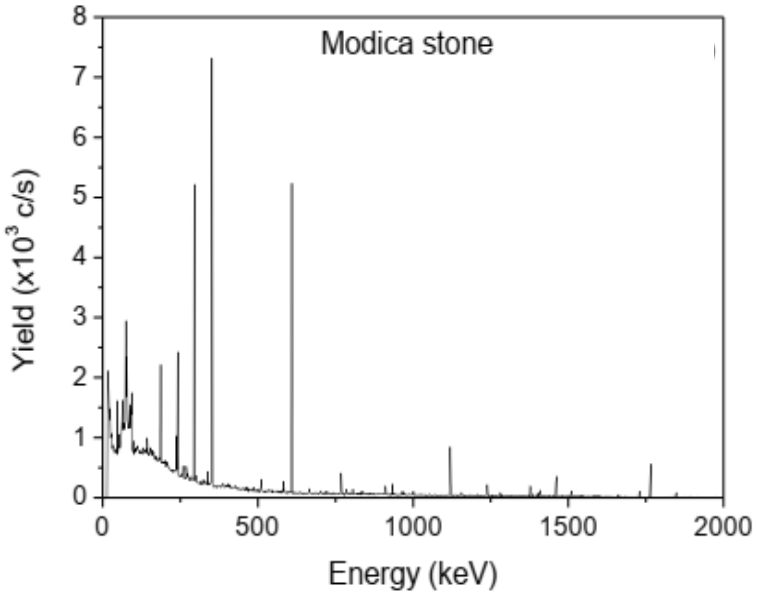
Sample	D (nGy h^{-1})	$AEDE_{out}$ (μSv y^{-1})	$AEDE_{in}$ (μSv y^{-1})	Ra_{eq} (Bq kg^{-1})	H_{ex}	H_{in}	I	I_α
Pietra di Lecce	76.8	94.2	377	166	0.4	0.9	0.6	0.82

3. F. Caridi, D. Chiriu, S. Da Pelo, G. Faggio, M. Guida, D. Majolino, G. Messina, M. Ponte, S.A. Ruffolo, V. Venuti

Natural radioactivity content in the "Pietra di Modica" stone and radiological health risk assessment: a case study

Proceedings of the «2024 IEEE INTERNATIONAL CONFERENCE ON Metrology for Archaeology and Cultural Heritage (METROARCHAEO)»





$$C\ (\mathrm{Bq\ kg^{-1}\ d.w.}) = \frac{N_E}{\varepsilon_E t \gamma_d M}$$

Sample	Specific activity		
	C_{Ra} (Bq kg^{-1} d.w.)	C_{Th} (Bq kg^{-1} d.w.)	C_K (Bq kg^{-1} d.w.)
Pietra di Modica	36.1 ± 6.1	2.2 ± 0.5	20.2 ± 3.8

$$I = (C_{Ra}/300 + C_{Th}/200 + C_K/3000)$$

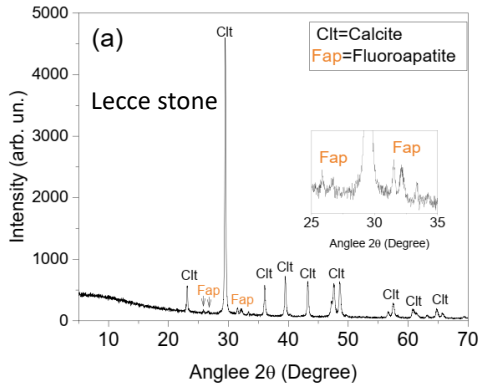
$$Ra_{eq}\ (\mathrm{Bq\ kg^{-1}}) = C_{Ra} + 1.43C_{Th} + 0.077C_K$$

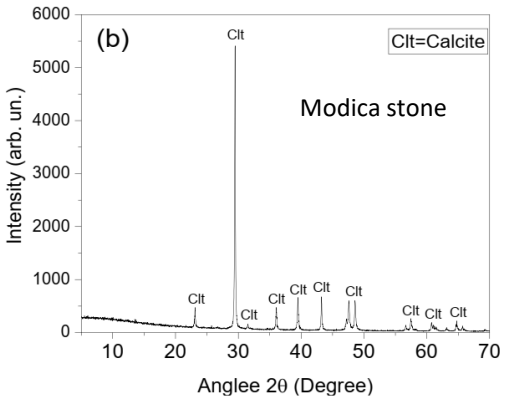
$$H_{ex} = (C_{Ra}/370 + C_{Th}/259 + C_K/4810)$$

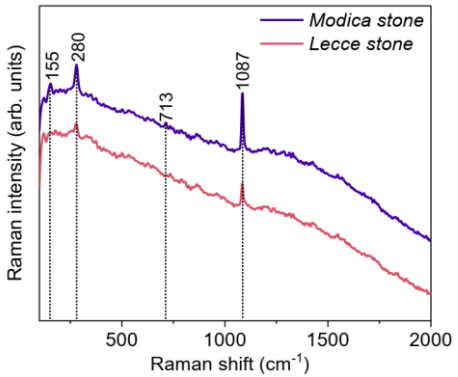
$$H_{in} = (C_{Ra}/185 + C_{Th}/259 + C_K/4810)$$

Sample	I	Ra_{eq} (Bq kg^{-1})	H_{ex}	H_{in}
Pietra di Modica	0.14	41	0.11	0.21

4. G. Faggio, G. Messina, D. Chiriu, S. Da Pelo, M. Guida, D. Majolino, M. Ponte, S.A. Ruffolo, V. Venuti, F. Caridi
Comprehensive Analysis of Lecce and Modica Stones Using X-Ray Diffraction and Raman Spectroscopy
Proceedings of the «2024 IEEE INTERNATIONAL CONFERENCE ON Metrology for Archaeology and Cultural Heritage (METROARCHAEO)»







Participation at conferences

1. 4th International Workshop on "MOdelling, SImulation and Data Analysis in Engineering and Physics Applications" (MOSIDA 2024) within The International Conference on Applied Physics, Simulation and Computing (APSAC 2024).
   Invited talk "Assessment of the radon exhalation and the radiological risk due to natural radioactivity content in the "Pietra di Lecce" building material: a case study"
   Roma, 20 – 22 June 2024

2. 2024 IEEE INTERNATIONAL CONFERENCE ON Metrology for Archaeology and Cultural Heritage (MetroArchaeo).
   Talk "Natural radioactivity content in the "Pietra di Modica" stone and radiological health risk assessment: a case study"
   Talk "Comprehensive Analysis of Lecce and Modica Stones Using X-Ray Diffraction and Raman Spectroscopy"
   Poster "Comparison of the Radon Exhalation Rate of building materials of particular historical and artistic interest: preliminary results on Ignimbrite Campana, Modica stone and Mendicino stone"
   Valletta Campus, Malta, 07-09 October 2024

https://athena.unime.it/